1 INTRODUCTION

1.1 Purpose

The purposes of this manual are to: 1) document procedures that were developed and used by the United States Environmental Protection Agency's (USEPA) Ecosystem Exposure Research Division (EERD) for the assessment of the physical and biological characteristics of headwater streams; and 2) provide a catalog of procedures to other groups with an interest in headwater stream assessment. Earlier EPA field operations manuals for running waters have focused on larger systems, including wadeable streams, non-wadeable rivers, and Great Rivers (e.g., Barbour et al. 1999, Lazorchak et al. 1998, 2000, Angradi 2006). There is a growing interest in headwater streams because human activities (e.g., road building, stormwater management) frequently intersect these widespread waterbodies. There is also considerable legal debate regarding extent of jurisdictional waters under the Clean Water Act and the role or nexus of various types of headwater streams to the integrity of downstream interstate waters (Nadeau and Rains *in press)*. Some states, like North Carolina and Ohio, have already began to initiate headwater stream classification methods for regulatory purposes (Ohio Environmental Protection Agency 2002, N.C. Division of Water Quality 2005).

This document provides methods specifically designed for assessing the hydrologic permanence and ecological condition of headwater streams. A universal, spatially-explicit definition of a headwater stream is lacking because stream size and drainage area varies with surrounding topography and geographic location. Regardless, headwater streams are important because they are the origins of the stream network and have unique ecological characteristics that separate them from larger, downstream waterbodies.

What are headwater streams?

Stream order is a measure of stream position within a drainage network system (Horton 1932, Strahler 1945, Shreve 1966). Headwater streams are typically considered to be first- and second-order streams (Gomi et al. 2002, Meyer and Wallace 2001), meaning streams that have no upstream tributaries (i.e., "branches") and those that have only first-order tributaries, respectively. Use of stream order to define headwater streams is problematic because stream-order designations vary depending upon the accuracy and resolution of the stream delineation (Mark 1983, Hanson 2001). Lack of agreement among maps with different mapping resolution is common when identifying headwater stream, determining stream order, and determining total stream (Figures 1-1 and 1-2). The designation of the mainstem (central tributary) origin is typically similar between the 1:100 000 and 1:24 000 scale maps. However, the 1:24 000 maps delineate more lateral tributaries (Figures 1-1A and 1-1B) and this can result in substantial differences of headwater extent. The total stream length within the Coweeta Creek watershed (16.3 km^2) in western North Carolina on a 1:500 000 scale map was only 3% of the length shown on a 1:24 000 scale map (Meyer and Wallace 2001). The smallest headwater streams are not designated as channels on topographic maps and may be difficult to discern in aerial photographs. Thus, stream-order designations based on maps are typically underestimated (Hughes

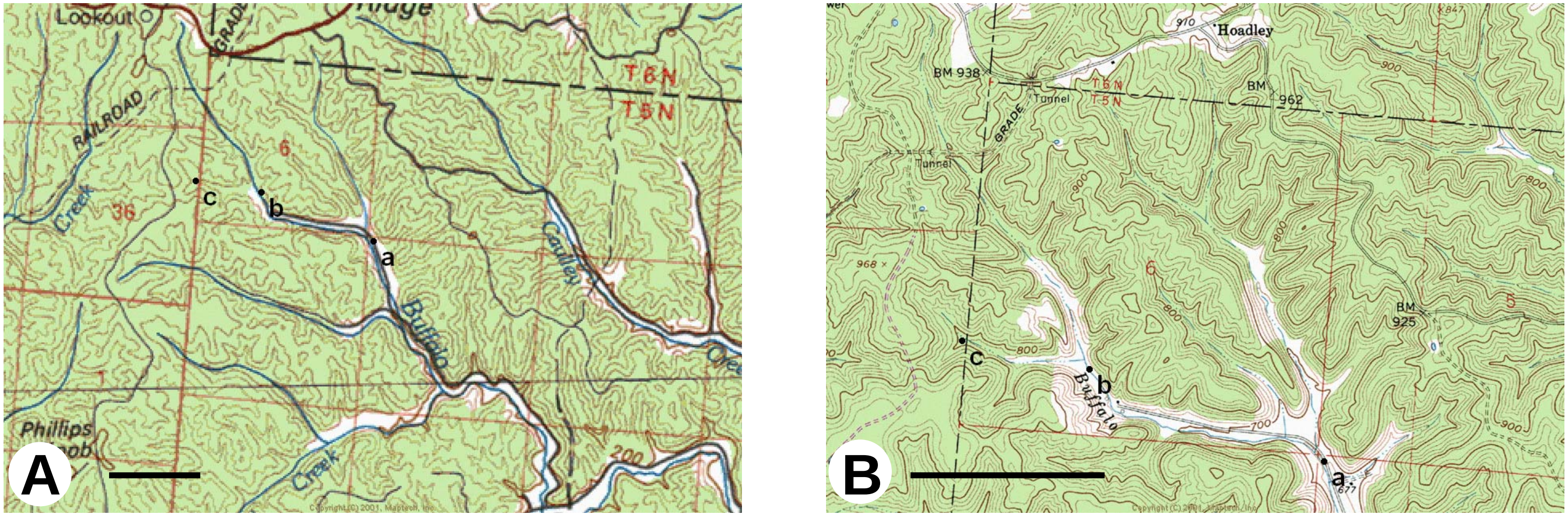

Figure 1-1 Portions of a 1:100 000 (A; Ironton 30 x 60 minute quadrangle) and a 1:24 000 (B; Gallia 7.5 minute quadrangle) scale United States Geological Survey (USGS) topographic maps illustrating the upper reaches of Buffalo Creek in Wayne National Forest (Lawrence and Gallia Counties, OH). Black circles and associated letters mark corresponding points on both maps. Black horizontal bars represent 1 km. Buffalo Creek at “a” is a second-order stream on the 1:100 000 map, but is a third-order stream on the 1:24 000 map. Likewise, Buffalo Creek at “b” is considered a first-order stream on the 1:100 000 map, but is a second-order stream on the 1:24 000 map. The point marked “c” is shown as a first-order stream on the 1:24 000 map, but is not designated as a stream on the 1:100 000 map. The number of first-order streams shown upstream of “a” on the 1:100 000 map is two, whereas the 1:24 000 map has five. Field surveys of this drainage would likely find ≥ 10X first-order streams upstream of “a”.

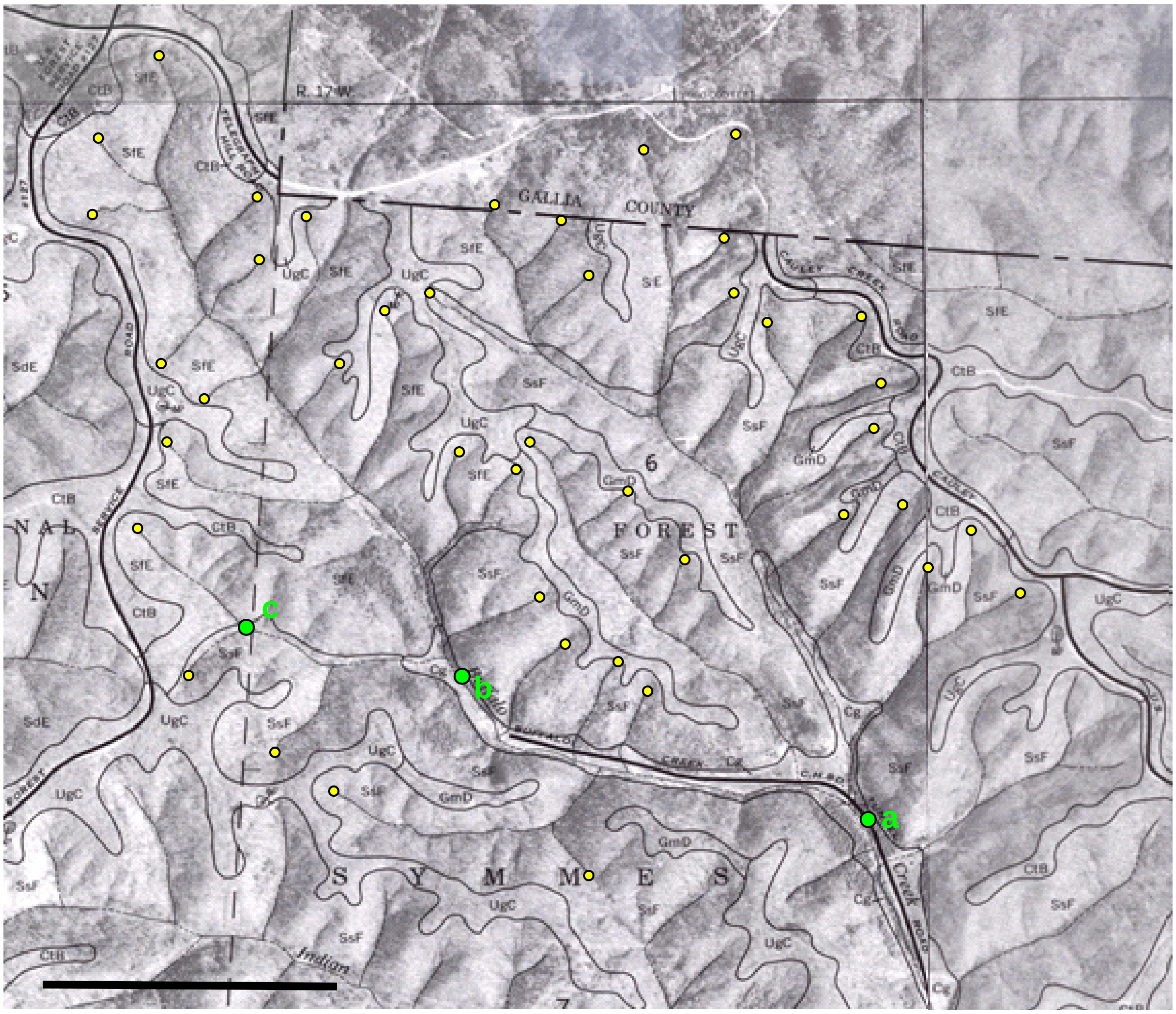

Figure 1-2 Portions of 1:15 840 United States Department of Agriculture (USDA) National Resources Conservation Service (NRCS) maps from Lawrence and Gallia Counties, OH illustrate the upper reaches of Buffalo Creek in Wayne National Forest (McCleary and Hamilton 1998). Green circles and associated letters mark corresponding points on maps in Figure 1-1. The yellow circles highlight the delineated stream origins. Black horizontal bars represent 0.5 mi (0.805 km). Buffalo Creek at "a" is a fourth-order stream, at "b" it is considered a third-order stream, and at "c" it is shown as a second-order. The number of first order streams shown upstream of "a" is 41.

and Omernik 1983), prompting some investigators to characterize such streams as zero-order streams (e.g., Brown et al. 1997). Most "blue line" designations on topographic maps are not based on field studies, but are "drawn to fit a rather personalized aesthetic" of the cartographer (Leopold 1994) or drawn with standards that exclude a proportion of headwater channels (Drummond 1974). Moreover, large scale aerial and satellite image databases (e.g., 30-m DEM) are typically too coarse to accurately identify most headwater channels, particularly in forested regions. Further development and more affordable application of Light Detection and Ranging (LIDAR) mapping technology provides the most promise for remotely recording the location and extent of headwater streams (e.g., Jarnagin and Jennings 2005). In addition, further work in understanding factors contributing to the evolution of stream channels will be useful for predicting the spatial distribution of headwater streams across the landscape (e.g., Montgomery and Dietrich 1988, 1992).

Headwater streams as monitoring units

Headwater streams are useful monitoring units owing to their extent (i.e., widespread and abundant), spatial scale and landscape position. Replicate streams of given treatments (e.g., types of land use/cover) and reference conditions, are more available for headwater streams because of their abundance across the landscape and relatively small watershed areas. Experimental studies are also more feasible (and ethically acceptable) in headwater streams and watersheds because they are easier to modify or perturb than downstream waterbodies (e.g., Likens et al. 1970, Wallace et al. 1999). Assessments of headwater streams can provide better resolution to diagnose cause and effect because they drain smaller areas with less land use heterogeneity than their larger counterparts. Flow of water from land to headwater channels is relatively short compared to larger rivers; therefore responses to land changes may be more rapidly detected. Because headwater streams have narrower widths and shallower depths than larger streams and rivers, a larger proportion of water flowing through headwater channels is directly contacting (and exchanging water and solutes with) the stream bed and banks at a given moment. Biogeochemical processes (e.g., denitrification) and biotic densities are often higher in the saturated sediments of beds and banks than in the water column. This increased wetted area to water volume ratio therefore suggests that headwater channels may strongly influence downstream water quality. Lastly, because headwater streams represent the dominant interface between surrounding landscapes and downstream surface waters, further understanding of the structure and function of headwater streams will improve our ability to protect all water bodies.

Headwater streams and drying

One of the most distinctive and ecologically influential characteristics of many headwater streams is natural drying. In contrast to perennial or permanent streams that maintain continuous surface flow throughout most years, temporary streams (e.g., intermittent, ephemeral) have a recurrent dry phase(s) (Comín and Williams 1994, Uys and O'Keefe 1997, Williams 2006). Not to be confused with temporary waters are aestival water bodies (more commonly used to describe ponds than streams, but see Johansson and Nilsson 1994). Aestival habitats are characterized by being shallow and permanent, but freeze completely during the winter (Daborn and Clifford 1974). Temporary streams are the dominant form of running waters in arid and semiarid regions (Zale et al. 1989, Dodds 1997, Gasith and Resh 1999. Nanson et al. 2002), but are also common in temperate and tropical areas (e.g., Clifford 1966, Chapman and Kramer 1991, Delucchi 1988, Feminella 1996). Regardless of climatic region, headwater streams are more prone to drying than larger streams because they have smaller drainage areas for capturing recharge and generally have higher topographic elevation (McMahon and Finlayson 2003, Rivenbark and Jackson 2004, Svec et al. 2005). The rate of drying, and predictability, duration, and frequency of dry periods vary with geographic setting and annual precipitation.

Variation in the temporal aspects of drying has been categorized by various classification schemes of temporary streams (Abell 1984, Poff and Ward 1989, Uys and O'Keefe 1997). Intermittent streams are typically identified as those that dry seasonally. During the dry season(s), frequently compounded by high evapotranspiration of watershed vegetation, the groundwater table may drop below the elevation of the streambed causing the stream to dry (Williams 2006). Ephemeral (or episodic) streams are usually dry except for several days immediately following precipitation. Surface flow in ephemeral channels is derived from surface runoff and shallow throughflow. Rather than having distinct, rigid boundaries, stream reaches classified as perennial, intermittent, and ephemeral may more accurately be described as dynamic zones within stream networks. The length or extent of these zones may be highly variable and is dictated by multiple factors (e.g., annual precipitation, evapotranspiration, land-use practices). The variable source area concept describes the dynamic zones as the expansion and contraction of flow within forested headwater systems (Hewlett and Hibbert 1967). Increases in discharge within small watersheds following a rain storm are rarely equivalent to the volume of rain fallen on the watershed. Much of the rain infiltrates into the soil and displaces subsurface water (already saturating the watershed) downslope into channels (i.e., throughflow or translatory flow). When this subsurface flow exceeds the capacity of the soil to transmit it downslope, water will be seen at the streambed surface and the wetted channel will extend upslope. Using a conservative tracer (NaCl) Genereux et al. (1993) measured the spatial and temporal variation in flow generation within a small watershed in Tennessee. They determined that two downstream, perennial springs generated most of the flow during late summer, but as discharged increased, flow was predominantly generated from upstream, temporary reaches.

The natural process of drying causes changes in physical and chemical conditions (e.g., loss of wetted habitat, reduced dissolved oxygen), which can exclude some species while allowing others to thrive (Boulton et al. 2000). Temporary streams may, therefore, harbor communities containing mixtures of unique endemics (i.e., locally distributed species) and opportunist cosmopolitans (i.e., widespread species). The biotic community will vary among temporary waters with duration of hydroperiod (Williams 1996) and timing of the hydrologic cycle (Boulton and Lake 1992, Fritz and Dodds 2002). The hydrologic permanence (duration and frequency of continuous surface flow) of headwater streams must be understood to avoid confounding effects of natural drying when assessing the ecological integrity or condition. Different ecological expectations are likely needed when assessing condition of perennial and temporary streams. Although the methods described in this manual were used to identify hydrologic regimes primarily in forested headwater streams, some of the methods can also serve to quantify the ecological integrity of non-forested headwater streams.

Organization of the manual

This manual is divided into three sections: 1) Assessment Design and Site Selection, 2) Physical Habitat Characterization, and 3) Biological Sampling. Sections are further divided into subsections, covering relevancy of a measure, detailed steps to collect data, lists of equipment and supplies, and alternative ways of quantifying measures (where applicable). References are provided at the end of each subsection to aid the reader. We refer to example field sheets for recording data throughout the manual. Complete copies of these field sheets are provided at end of the manual in Appendix 1. The procedures described in this document are intended to maximize the information gained for amount of resources expended. The initial intent of most procedures described is to collect information that characterizes the hydrologic permanence of stream reaches (i.e., indicators); however, most measures are also commonly used in stream condition assessments (e.g., macroinvertebrates, substrate size).

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